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ABSTRACT

Cognitive psychologists have recently alluded to the role analogies might play in learning unfamiliar topics. However, since the use of analogies in science teaching has not been adequately addressed, analogies mean different things to different people. Therefore, a model for the teaching of scientific analogies is proposed. A theoretical framework for "The General Model of Analogy Teaching" (GMAT) is provided first, followed by a detailed description of the model. Points covered in the framework include: (1) definition of the analogy; (2) analogical learning; (3) variables related to analogical learning; (4) evaluating the outcomes of analogical learning; and (5) limitations of using analogies in teaching. The nine GMAT stages described include: measuring some of the students' characteristics related to analogical learning in general; assessing students' prior knowledge about the topic to be taught; analyzing the learning material; judging the appropriateness of the analogy to be used; determining the characteristics of the analogy to be used; selecting the instructional strategy and medium of presenting the analogy; presenting the analogy to students; evaluating the outcomes of using the analogy in teaching; and revising the stages of the model. (Author/JN)

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# TEACHING SCIENTIFIC ANALOGIES: A PROPOSED MODEL

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## ABSTRACT

The purpose of this paper is to propose a model for teaching scientific analogies. This model is called: "The General Model of Analogy Teaching (GMAT)." A theoretical framework is developed first for this model. The following points are covered in this framework: 1)definition of the analogy, 2) analogical learning, 3) variables related to the analogical learning, 4) evaluating the outcomes of analogical learning, and 5) limitations of using analogies in teaching. The General Model of Analogy Teaching proceeds in the following nine stages: 1) Measure some of the students' characteristics related to analogical learning in general, 2) assess the prior knowledge of the students about the "topic" to be taught, 3) analyze the learning material of the "topic" to be taught; 4) judge the appropriateness of the analogy to be used, 5) determine the characteristics of the analogy to be used, 6) select the strategy of teaching and the medium of presenting the analogy, 7) present the analogy to the students, 8) evaluate the outcomes of using the analogy in teaching, and 9) revise the stages of the model.

## INTRODUCTION

Students often lack the background knowledge to learn some difficult and unfamiliar topics such as atom, Ohm's Law, and living cells. One effective way to deal with this problem is to provide those students with an interpretive bridge between the unfamiliar topics and the knowledge which students have. Cognitive psychologists have suggested that such a bridge can be provided through the use of analogy. Attempting to specify the influence of background knowledge on learning, they have alluded the role the analogy might play in bringing relevant background knowledge to bear in learning new topics (Hayes & Tierney, 1982).

Used as a teaching strategy, analogy provides a comparison which can explain something difficult to understand by pointing out its similarities to something easy to understand or already understood. For example, the camera can be used to teach how the human eye works. Human eye is analogous to the camera in different ways: the pupil of the eye is similar to the aperture of the camera, the retina of the eye has some similarity to the film of the camera and so on. Another example is the atom/solar system analogy known as Rutherford's solar system model of the hydrogen atom (Gentner, 1989). Here the familiar concept of the solar system which consists of sun and planets used to facilitate learning of another unfamiliar concept, the hydrogen atom. The nucleus of the atom is analogous to the sun and the electrons analogous to the planets. Other examples of scientific analogies are available by Dreistadt (1968), Gentner (1980), and Oppenheimer (1956).

Analogies do not always facilitate the learning of unfamiliar "topics." Teaching with analogies appears to have some limitations. For example, using analogy could result in some misconceptions when the learners take the analogy literally such considering the pupil of the eye as exactly as the aperture of

the camera. Other limitations are given later in this paper.

Unfortunately, the use of analogy in science teaching has not been well covered; consequently, the use of analogies means different things to different people (Mayer, 1983). More seriously, analogies "are often used in the wrong sense or with unjustified implications which result in propogation of erroneous concepts," (Weller, 1970, p. 113). It seems that there is no common view for teaching analogies. In this connection, Leatherdale (1974) added:

> "Analogies have been presented in an occasional, opportunistic, discursive way, subject to the whims of the teacher, the vagaries of the course structure and the idiosyncracies of textbooks." (p. 215)

These problems with the use of analogies occur not only in the regular classroom but also in research. Previous studies that dealt with instructional application of analogies "employed different forms of analogies, different methodologies and measured different learning outcomes. Taken as a whole, they have yielded contradictory results," (Polland, 1978, p. 2). Seemingly, both teachers and researchers need a model that guides the teaching of analogies.

Purpose

The purpose of this paper is to propose a model for teaching scientific analogies. This model is called: "The General Model of Analogy Teaching, " (GMAT). First, the model is flexible to provide teachers and researcher with different alternatives from which to choose. Second, the model exposes many areas of research that are relevant to teaching analogies that need investigation. A theoretical framework for this model is provided first, followed by a detailed description of the model.

## THEORETICAL FRAMEWORK

The following points will be covered in this framework:

1. Definition of the analogy

2. Analogical learning
3. Variables related to the analogical learning
4. Evaluating the outcomes of analogical learning
5. Limitations of using analogies in teaching

Definition of the analogy

What does the term analogy imply? About one hundred years ago Mill pointed out: "there is no word...which is used more loosely, or in a greater variety of senses than analogy," (quoted in Weller, 1970, p. 113). Today we have the same problem. The term analogy still means different things to different people (Mayer, 1983). Most of the definitions available are vague and provide little criteria for selecting or even constructing analogies for instructional purposes (Polland, 1978). A new definition is therefore proposed here based on its four components. They are: 1) topic, 2) analog, 3) analogous attributes, and 4) irrelevant attributes.

1) Topic -- the unfamiliar learning material to be taught (the target domain of learning). The topic could be a concept, principle, procedure (Reigeluth, note 1), theory (Weller, 1970) or problem to be solved (Gick & Holyoak, 1980). The eye is the "topic" in the eye/camera analogy. The atom is the "topic" in the atom/solar system analogy.

2) Analog (Analogue) -- the familiar and visualizable materials used to facilitate the learning of the "topic." The camera is the analog in the eye/camera analogy, while the solar system is the analog in the atom/solar system analogy.

It must be noted that a concept may function as a "topic" in one analog and as an "analog" in the other. For example, if the atom is used to facilitate the learning of the solar system, the atom is the "analog" in this case, while the solar system is the "topic."

3) Analogous Attributes --the conjoint attributes or corresponding at-attributes shared by both the "topic" and the "analog." Attributes can be viewed as analogous when: a) they exhibit a physical or structural similarity; i.e., they look similar or are arranged in a similar configuration; b) they exhibit a functional similarity; i.e., they act in a similar way; c) they exhibit a consequential similarity; i.e., a similar or the same underlying cause creates similar effects (Polland, 1978). The atom/solar system analogy has all three types of these analogous attributes:

> The atom and the solar system have physical similarities (both are comprised of smaller spheres orbiting larger spheres); they have functional similarities (the smaller spheres are said to spin on an axis), and they have consequential similarities (the electric force and gravity are viewed as similar causes having similar effects). The electric force and the gravitational force are also similar because they both vary inversely with the square of the distance between their respective sources. (Polland, 1978, pp. 12-12)

There should be at least one analogous attribute between the "topic" and the "analog," otherwise the term analog is not applicable.

4) Irrelevant Attributes -- the different or mismatching attributes found between the "topic" and "analog." For example, some attributes of the atom are different than those of the solar system such as the sun being massive while the nucleus is very tiny, the sun is hot while the nucleus is not and so on (Gentner, 1980).

The irrelevant attributes are part of the nature of the analogy. The term analogy is not applicable when the attributes of the "topic" and the "analog" are identical (as in the case of one human eye and the other) or literally similar (as in the case of a human eye and the eye of another mammalia, i.e., rabbit) (see: Gentner, 1980; Ortony, 1979 for details about the differences between analogy and both identity and literal similarity).

In other words, the term analogy is probably applicable only when both the "topic" and "analog" belong to different schemata. The term "schema" (singular

of schemata) is often used to refer to the general knowledge possessed about particular domains (Alba & Hasher, 1983). Schemata are considered to be clusters of knowledge (Winn, 1982). More details about schemata are given by Rumelhart (1980). It can be assumed that in the eye/camera analogy, the human eye belongs to the "eye schema," while the camera belongs to the "camera schema." The two schemata are not identical or literally similar; they are analogically related.

Accordingly, pictures, physical models, graphs and other illustrations are not considered as "analogs" when they belong to the same schema as that of the "topic." For example, the term analogy is not applicable when we use a physical model or a picture of the human eye as a teaching aid to explain how the eye works. Both the model and the picture belong to the same schema as the "topic," the human eye.

Analogical Learning

Analogical learning has been explained from a variety of theoretical perspectives such as gestalt psychology (Dreistadt, 1968); Ausubel's theory of meaningful verbal learning (Royer & Cabel, 1975, 1976); assimilation encoding theory (Mayer, 1983), structure mapping theory (Gentner, 1980), elaboration theory (Stein, Witham, Reigeluth, (note 2), and schema theories (e.g. Rumelhart & Norman, 1981). Probably, the schema theories are the best paradigms available to explain some of the aspects of analogical learning (Gick & Holyoak, 1980; Hayes & Tierney, 1980; Winn, 1982).

The following version of analogical learning has been modified from one of the schema theories (Rumelhart & Norman, 1981). It should be interpreted with caution since it oversimplifies the propositions of this schema theory. Some new propositions are added by this author to the theory to account for some ideas presented later in this paper.

Whenever one encounters a new learning material (topic), he or she seeks to interpret it in terms of existing schemata (background knowledge). If one succeeds, he or she understands this material and no new schemata needs to be created. Occasionally, however, there are no existing schemata that can offer a satisfactory account for understanding this new material. In this case, it is assumed that the next best schema or "analog schema" be found. The "analog schema" should have some similar as well as irrelevant attributes with this material (the topic). Presumably, the "analog schema" will work as a model for generating a new schema for the "topic." The similar attributes (analogous attributes) will be carried over or transferred from the "analog schema" to the new schema, "the topic schema." (see: Figure 1).

It is also possible that some of the irrelevant attributes will also be transferred later from the "analog schema" to the new schema or vice versa. This may cause learning misconceptions. For example, when the camera is used as an "analog" to the eye, it may lead someone to think that the retina uses film to work exactly like the film of a camera.

Therefore, analogical learning might be effective when the subject: 1) transfers the analogous attributes from the "analog" schema to that of the "topic,"; and 2) isolates the irrelevant attributes of the "analog schema" from that of the "topic."

Variables Related to Analogical Learning

Analogical learning, as described above, seems to be related to some of the students' characteristics as well as instructional variables.

Student's Characteristics

There are many student's characteristics that are thought to be related to

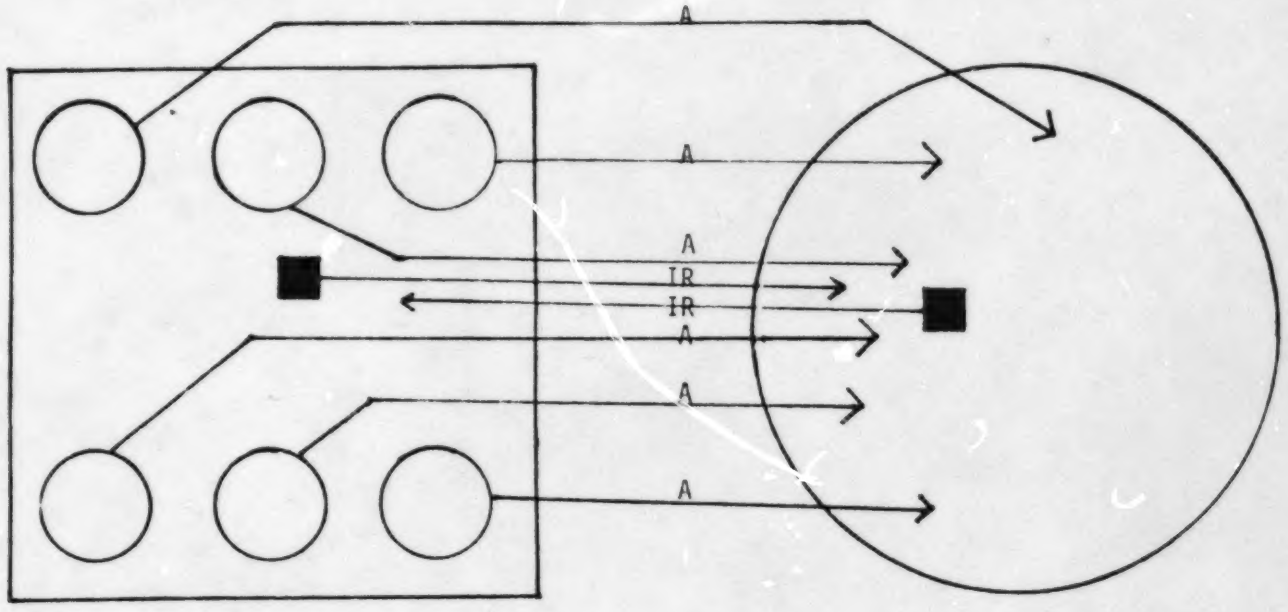


Figure 1: The transfer of the analogous attributes and the irrelevent attributes between the "analog schema" and the "topic schema"

analogical learning: 1) familiarity with the "analog", 2) Prior knowledge of the "topic", 3) Analogical reasoning ability, 4) Piagetian cognitive levels, 5) Visual imagery, 6) Cognitive complexity.

1) Familiarity with the Analog

The student who is not familiar with the "analog" (e.g., solar system) may not use it to study the "topic" (e.g., atom). The unfamiliar analog may distract the student's attention from studying the "topic." Also, the unfamiliar analog may add a new load to the learning situation since the learner is required to understand both the "analog" and the "topic." Furthermore, using an unfamiliar "analog" might push some students into seeking another more familiar analog. This familiar analog could facilitate or hinder the learning depending upon how analogous it is to the "topic." Gabel and Sherwood (1980a) found that students who were not familiar with "analogs" did not benefit from the analogies presented to them.

2) Prior Knowledge about the Topic

According to Royer and Cable (1975, 1976), and Mayer (1983) analogies would produce best results when the learning material (the topic) is unfamiliar, i.e., the student has not yet developed a schemata for this material.

Providing students with analogies when they possess relevant background knowledge may distract the learner's attention away from the target learning material. It may also add an unnecessary load to the learning of materials.

3) Analogical Reasoning Ability

According to Willner (1964) analogical reasoning includes "the extraction of a relationship in one realm, construction of a closely equivalent relationship in a different realm, and a careful inspection to see that both relationships are closely matched" (p. 481). Examples of forms of analogical reasoning are:

a) A is to B as C is to _____?

b) Bird is to air as fish is to _____?

Analogical reasoning seems to be required in the process of using the analogous attributes to link the "analog schema" with the "topic schema."

Accordingly, one would hypothesize that students with high analogical reasoning ability would benefit more from the analogies than other students who are low in this ability. This hypothesis needs empirical verification (Dowell, 1968).

More details about the analogical reasoning and how it is measured can be found elsewhere (e.g., Dowell, 1968; Sternberg, 1977).

4) Piagetian Cognitive Levels

Most analogies have a concretizing function: they render unobservable attributes of the abstract topics (e.g., atom) perceptible by comparing them with concrete, imaginable "analogs" (e.g., solar system). Accordingly, one might expect that the concrete operational students will benefit from the use of analogies to study the abstract concepts. The formal operational students may also benefit from the analogies (Goodstein & Howe, 1978).

Few studies have investigated the differential effect of scientific analogies on the concrete operational students versus formal operational students (Gabel & Sherwood, 1980 a, b). No definite conclusion could be drawn from these studies.

One problem that might limit use of analogies for concrete operational students is that these students might lack correlational reasoning (Gabel & Sherwood, 1980a). This type of reasoning, developed only during the formal stage, refers to "the thought patterns individuals use to determine the strength of mutual or reciprocal relationships between variables" (Lawson, Adi, & Karplus, 1979, p. 420). Learning by analogy requires such relationships between the "topic" and the "analog." Accordingly, it could be hypothesized that students who possess correlational reasoning will benefit from analogies more than other who do not. This hypothesis has not been empirically validated.

Details about the Piagetian cognitive levels are available elesewhere (e.g., Inhelder & Piaget, 1958). The classroom tests that measure these levels can be found in Lawson (1978).

5) Visual Imagery

Visual imagery seems to play a role in learning by analogy. This role is not completely understood. The process of transferring the attributes of the "analog" to the "topic" may involve visual images (Winn, 1982).

History of science is replete with examples that show this role of visual imagery (see: Dreistadt, 1968). An example is that of Kekule who discovered the "benzene ring" (usually represented as a hexagon). About this discovery, Kukule said:

> I turned my chair to the fire and dozed. Again the atoms were gamboiling before my eyes. This time the smaller groups kept modestly in the background. My mental eye, rendered more acute by visions of this kind, could now distiguish larger structures, of manifold conformation; long rows, sometimes more closely fitted together, all twining and twisting in snakilike motion. But look! What was that? One of the snakes had seized hod of its own tail, and the form whirled mockingly before my eyes. As if by a flash of lightening I awoke. (Quoted in Dreistadt, 1968, p. 102)

More details about this visual imagery and how it is measured is available by Durio (1979) and Ernest (1977).

6) Cognitive Complexity

According to MacNeil (1974), "cognitive complexity is a cognitive structural approach to individual differences. It is hypothesized that persons possess cognitive structures for processing information. A person's cogntive structure has two main components: a discriminating structure, referring to the breaking up, partitioning, etc. of stimulation, and an integrating structure, referring to how partitioned parts are related, combined, added, etc." (p. 4). Persons vary in the complexity of these structures such that persons are generally classified as cognitively complex if they are high on the discriminative structure and/or the integrative structure and cognitively simple if they are low on both these

structural indices.

Cognitive complexity, as indicated above, could be related to the analogical learning. The integrative structure might be utilized when the students relate the analogous attributes of the "analog" to that of the "topic." The discriminative structure could function when the students' isolate the irrelevant attributes between the "analog" and the "topic" (Winn 1982).

Instructional Variables

Analogical learning may also be related to many instructional variables: 1) complexity of the analogy, 2) degree of concreteness of the analogy, 3) number of the analogs included in the analogy, 4) format of presenting the analogy, 5) teaching strategies of the analogy, and 6) medium of presenting the analogy.

1) Complexity of the analogy

Polland (1978) referred to the complexity of the analogy as the number of conjoint (analogous) attributes that can be interpreted from an analogy statement. The analogy complexity can be determined by raters. They evaluate the analogy and infer the number of the analogous attributes shared by both the "analog" and the "topic." Polland developed the "analogy checklist" to be used for this purpose. An example of a checklist is shown in figure 2. At the top of the checklist is the analogy statement: Electrons flow through a wire like water flows through a pipe. The attributes of the topic are grouped for reference purposes under four headings: electron, wire, power source, and resistance. To use the checklist, the rater first reads the analogy statement at the top of the checklist. Then the rater reads the list of attributes and the category headings. Around the middle of the checklist are a series of yes-no response alternatives, one for each "topic" attribute. At the top of this series is the question, "Does the 'analog' have related or similar attributes to the 'topic'?" To respond to this question, the rater presumably poses implicit questions about the existence of attributes in the "analog" that are similar to the "topic" attributes. For example, electrons are uniform in size and composition, move

ANALOGY STATEMENT: Electrons flow through a wire like water flows through a pipe.

| | Does Analog Have Related or Similar Attributes to Topic? | | Topic Attributes |
|---|---|---|---|
| | | | Electrons |
| THE ANALOG FOR "ELECTRONS" IS *water* ? | 1. yes no | | 1. are uniform in size and composition |
| | 2. yes no | | 2. move about in random directions |
| | 3. yes no | | 3. move about in a high velocity |
| | 4. yes no | | 4. move in a net direction down a conductor if an external force is applied |
| | 5. yes no | | 5. number of them vary in different conductors |
| | 6. yes no | | 6. number in conductor remains constant |
| | 7. yes no | | 7. number of them that are free to move about depends upon the conductor and external forces |
| | 8. yes no | | 8. have characteristic force which it exerts |
| | 9. yes no | | 9. can transfer kinetic energy to other bodies |
| | 10. yes no | | 10. can give up energy as heat |
| | 11. yes no | | 11. "collide" with each other and other bodies |
| | | | Wire |
| THE ANALOG FOR "WIRE" IS *pipe* ? | 12. yes no | | 12. uniform in its dimension |
| | 13. yes no | | 13. cylidrical in shape |
| | 14. yes no | | 14. length and area can vary |
| | 15. yes no | | 15. has dimension of volume |
| | 16. yes no | | 16. temperature of it can vary |
| | 17. yes no | | 17. composition can vary |
| | 18. yes no | | 18. external force applied at one end can be transferred through it to the other end |
| | 19. yes no | | 19. have entities (electrons) which move about inside it |
| | 20. yes no | | 20. have entities (molecules) inside it which do not move about freely |
| | 21. yes no | | 21. have entities (molecules) inside it which will determine the freedom of other entities to move about |
| | | | Power Source |
| | 22. yes no | | 22. produces the force which causes the entities (electrons) to flow in a net direction |
| THE ANALOG FOR "POWER SOURCE" IS *pump* ? | 23. yes no | | 23. increasing its energy potential will result in an increase in the flow |
| | 24. yes no | | 24. the flow (of electrons) is proportional to the strength of the force it produces |
| | | | Resistance |
| | 25. yes no | | 25. increase as length (of conductor) increases |
| THE ANALOG FOR "RESISTANCE" IS *friction* ? | 26. yes no | | 26. increase as temperature (of conductor) increases |
| | 27. yes no | | 27. increases as area (of conductor) decreases |
| | 28. yes no | | 28. varies in different conductors due to their composition |
| | 29. yes no | | 29. increasing it will reduce the flow when the force is kept constant |
| | 30. yes no | | 30. when increased, causes entities to give up more energy |

Figure 2: Analogy checklist (modified from Polland 1978)

about in random directions, etc. The rater might ask the following questions about the analog; water: are the water molecules uniform in size and composition? Do the water molecules move in random directions, etc. To respond to these self-imposed questions, the rater is asked to circle either "yes" or "no" for each attribute considered. The number of "yeses" refer to the number of analogous attributes infered from the analogy, i.e., complexity of the analogy (see: Polland, 1978, for more details).

Readers who will use this checklist to estimate the complexity of this analogy will discover unexpectedly that it has low complexity. This analogy is widely used in teaching electricity, however.

Polland (1978) found that students receiving the high complexity analogies scored higher on a post-test than students receiving low complexity analogies. The high and low complexity analogies included the same "topic," however, they were different in that the "analog" used was dissimilar in each case. The post-test measured rule-using and problem-solving in electricity.

2) Degree of concreteness of the analogy (Physical, Pictorial and Verbal)

Analogies differ according to the degree of concreteness of both the "analog" and the "topic." They could be: a) physical (e.g., real camera or eye); b) pictorial (e.g., picture of a camera or eye); c) verbal (e.g., passage describing a camera or eye); and d) a combination of any of the preceding. The "topic can also be symbolic (e.g., Ohm's Law; R=V/I). The "analog" and the "topic" may differ in degree of concreteness (e.g., real camera/picture of the eye).

The effect of combinations of different degrees of concreteness of the "topic" and the "analog" on analogical learning has not been subjected to empirical investigations. These combinations could interact with some of the learner variables stated above, such as Piagetian cognitive levels and visual imagery.

3) Number of the "analogs" included in the analogy

Analogies could be classified according to the number of "analogs" used in

one analogy into 1) single analogies; and 2) multiple analogies. A single analogy usually includes only one "analog." For example, the atom/solar system analogy includes one "analog", i.e., the solar system. On the other hand, a multiple analogy includes more than one "analog" that belongs to different domains of knowledge or schema. An example of multiple analogy follows: Cells are the building blocks of organisms. Cells are like tiny factories. They make almost everything an organism needs, such as parts of growth and reproduction. Cells are energy transformers. They change unuseable forms of energy to forms that can be used to do cell work. In addition, cells act like a tiny computer, storing information that can produce an entirely new organism. In this analogy, cells were analogous to the following analogs: the building blocks, tiny factories, energy transformers, and tiny computers.

No investigations of the comparable effect of single analogies versus multiple analogies on analogical learning are available in the literature.

4) Format of presenting the analogy (Mixed format & Separate format)

Analogies are normally presented to the students in either the mixed format or the separate format. In the mixed format both the "topic" and the "analog" are intertwined and compared in the unit of instruction; e.g., the lesson or the reading passage. An example of the mixed format of analogy is:

> The circulatory system is like the sanitary system of a city. In both there is a pumping station, pipelines with varying sized pipes, a filtration plant, an exchange terminal and capacity for disposal waste (Eggen, Kauchak & Harder, 1979, p. 282).

Alternatively, in the separate format, both the "topic" and the "analog" are presented independently of each other. For example, the sanitary system and the circulatory system are presented as separate from each other. Then the comparison is made between the two at a later time.

The effects of a mixed format presentation versus the spearate format have not yet been investigated.

5) Teaching strategies of the analogy

Three major strategies can be used to teach analogies:

a) Student Self-Developed Analogy Strategy

In this strategy, students are encouraged to develop their own "analogs" to the new learning material (e.g., atom). No prior "analogs" are given to them. A classroom discussion can be held to present everyone's analogy. This strategy may help students to use the analogies in their thinking. However, it may have little value in learning difficult concepts. Students who lack background knowledge (schemata) about these concepts may encounter difficulty to develop appropriate "analogs" for these concepts.

b) Guided Teaching Strategy

According to this startegy, students are actively manipulating the analogy mentally and physically, i.e., they infer the analogous attributes as well as the irrelevant attributes between the "topic" and the "analog." This manipulation is guided by the teacher. An example of teaching some initial ideas about "the atom" to young learners using the guided strategy follows:

> Imagine yourself standing in the center of a large open space, a field or gymnasium. Look down and find a speck of dust or dirt. Take ten giant steps backward, but keep your eyes on the speck. Notice how tiny the speck appears from this distance. Imagine the speck is the nucleus of an atom; you are the electron. Dance around the speck. How does it feel? What power do you have as an electron? Rest and slowly return to the room. Open your eyes and share your experience. (Hassard, 1982, p. 30).

c) Expository-teaching strategy

In this strategy, the analogy is presented by the teacher or a book or by other mediums (see below) and students passively assimilate it, i.e., they do not infer the analogous attributes or the irrelevant attributes of the analogy.

The above strategies could have different effects on analogical learning. Few empirical results are available about the effect of some of these strategies on this learning (see: Dowell, 1968; Gabel, Sherwood, 1980a, b).

6) Medium of Presenting the Analog

The major mediums used to present analogies to students are: 1) the written medium, normally a prose passage that includes the analogy; 2) oral presentation by the teacher; 3) audio cassette, television and slide presentations; 4) demonstrations; 5) role playing; 6) games; 7) manipulative models; 8) picutres; and 9) graphs.

The effects of different mediums of presenting analogies on analogical learning has not yet been investigated.

Evaluating the Outcomes of Analogical Learning

In the light of the earlier discussion of analogical learning, the major outcomes of this learning might include:

1. Increase in the knowledge of the attributes of the "topic" as a result of the transfer of the analogous attributes from the "analog schema" to "topic schema."
2. Misconceptions in learning of the "topic" or the "analog" as a result of the failure of the learners to isolate irrelevant attributes of the "analog schema" from that of the "topic."

Prior to measuring these outcomes the evaluator needs to know whether or not the students have used the "analog" to study the "topic."

Accordingly, the following three steps are provided to evaluate the outcomes of analogical learning:

1. determine whether or not students have used the "analog" to study the topic.

It is very important for teachers as well as researchers to know whether the students have used the "analog" to study the "topic." This knowledge will help them to explain the results obtained in the next two steps. Such knowledge could be gained through any of the following measures: oral questions, clinical interviews, and written achievement tests. Items of these measures could be similar to those used in the analogical reasoning tests. An example of these items is: (see: atom/solar system analogy):



A planet is to the Sun as ____ is to ____ ?

If it is found that the students have not used the "analog" to study the "topic," a few explanations could account for it. First, the "analog" was not attended. Second, the "analog" was difficult to understand. Finally, the "topic" was easy to understand without the aid of the "analog." Other explanations are possible.

2. assess the students' knowledge of the attributes of the "topic."

This assessment could proceed as follows:

a) A list of the basic attributes of the topic is prepared (see, for example, the 30 attributes of the topic mentioned in Figure 2).

b) The students knowledge of these attributes is measured by written tests or clinical interviews or other measures.

c) The number of correct attributes (from the list) known by the students can be used to establish an index indicating their knowledge about the attributes of this topic.

When it is found that this index is low, many explanations could account for it, such as: a) the student might not have used the "analog" to study the "topic;" b) the "analog" might not have been highly "analogous to the "topic," i.e., the "analog" has low complexity (see complexity of the analog, above.); c) some of the students' characteristics might hinder the transfer of the analogous attributes from the "analog schema" to that of the "topic;" d) the student fails to isolate the irrelevant attributes of the "analog schema" from that of the "topic." (see next step).

On the other hand, when this index is relatively high, it might mean that the analogous attributes have been transferred successfully from the "analog schema" to the "topic schema."

Of course analogies may help the students to acquire only the attributes of the "topic" that are analogous to the "analog." Also, the "analog" will not help

students acquire knowledge of technical facts about the "topic." For example, the atom/solar system analogy will not help the students acquire knowledge of the mass of the protons or the nuetrons.

3. identify any misconceptions resulting from using the analogy

As indicated earlier, some misconceptions might result from taking the relationship literally between the "topic" and the "analogy." These misconceptions could be in the learning of the "topic" as well as the "analog." The misconceptions might be identified through oral questions, clinical interviews, written achievement tests, and others.

Limitations of Using Analogies on Teaching

As it appears in several places in this paper, analogies do not always facilitate learning unfamilar "topics." Teaching with analogies seems to have some limitations. Basic to these limitations are:

1. Analogies could have little or no positive facilitative effect when a) the "analog" used is unfamiliar to the students; b) the students possess enough background knowledge about the "topic"; c) students probably lack some abilities such as analogical reasoning, visual imagery and cognitive complexity (see students' characteristics above); and d) the number of analogous attributes of the analogy is limited, while the number of irrelevant attributes is superfluous.

2. When the students take the analogy literally some misconceptions in the learning of the "topic" and/or "analog" might result.

3. Teaching with analogies will not help students acquire all the basic attributes of the "topic." Nor will this teaching help students acquire some technical facts or information about this "topic."

## THE GENERAL MODEL OF ANALOGY TEACHING (GMAT)

The General Model of Analogy Teaching (GMAT) proceeds in the following nine stages (figure 3):

1. Measure some of the students' characteristics related to analogical

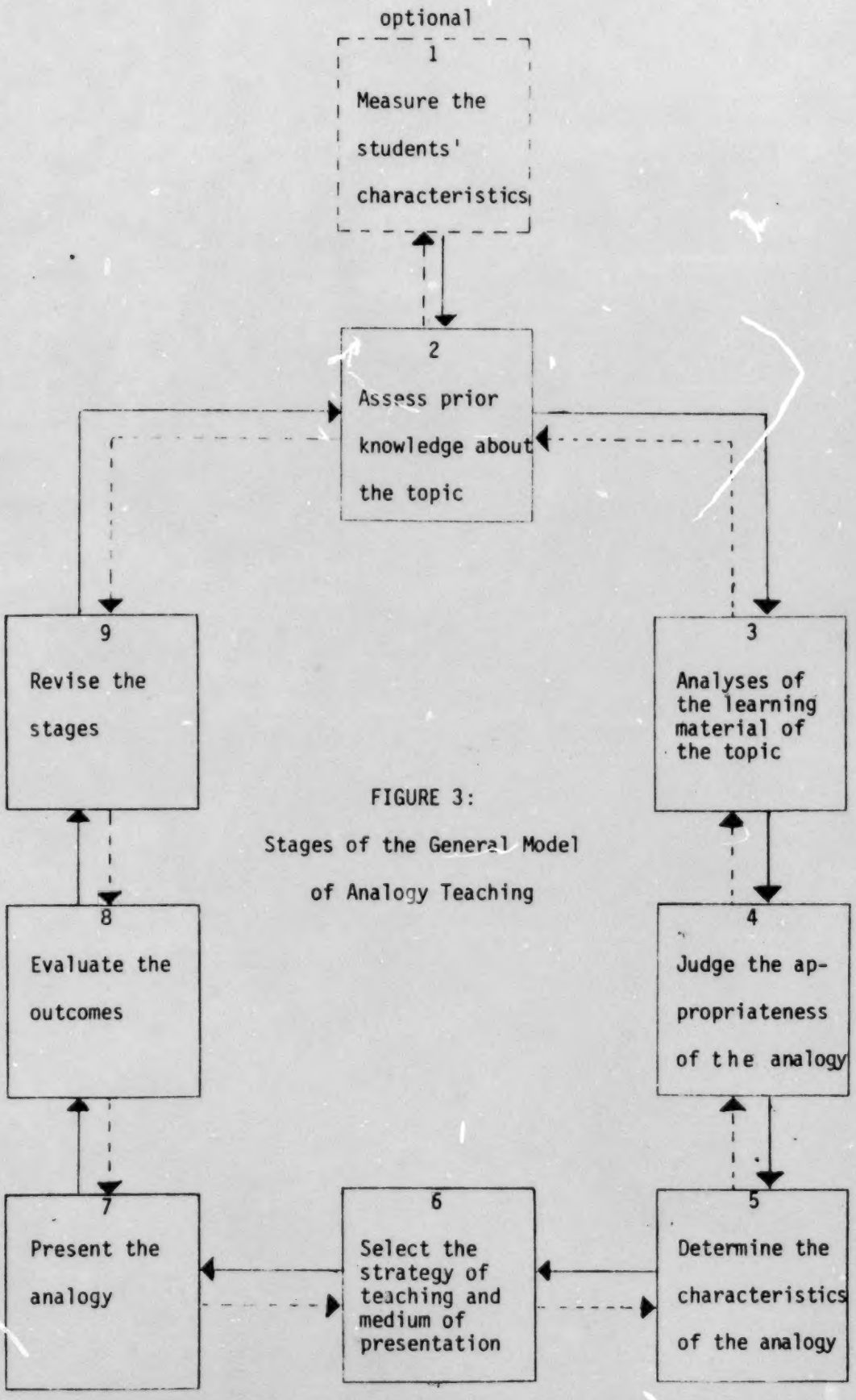


FIGURE 3:

Stages of the General Model of Analogy Teaching

learning in general.

2. Assess the prior knowledge of the students about the "topic."
3. Analyze the learning material of the "topic."
4. Judge the approrpiateness of the analogy to be used.
5. Determine the characteristics of the analogy to be used.
6. Select the strategy of teaching and the medium of presenting analogy.
7. Present the analogy to the students.
8. Evaluate the outcomes of using the analogy in teaching.
9. Revise the stages of the model.

Stage 1: Measure some of the students' characteristics related to analogical learning in general.

The following characteristcs may need to be measured prior to teaching the analogies to the students (see the framework for details):

1. Analogical reasoning ability
2. Piagetian cognitive levels
3. Visual imagery
4. Cognitive complexity

Note: Teachers may consider this stage optional until enough evidence is gathered from research concerning the relationship between these four variables and analogical learning. For researchers, some or all of these four variables and others may be selected for aptitude treatment interaction studies (Cronbach & Snow, 1977).

Stage 2: Assess the prior knowledge of the students' about the "topic."

If the students possess enough background knowledge about the "topic" to be taught, analogies may not help (see the framework) and another approach of teaching could be used. Note: Teachers may use oral questions to assess this prior know-

ledge. Researchers as well as teachers can also use questionares, clinical interviews and achievement tests for the same purpose.

Stage 3: Analysis of the learning material of the "topic".

The purpose of this analysis is to determine whether or not the learning material of the "topic" contains built in analogies. When this material contains built-in analogies, these analogies should be judged according to some criteria (see next stage). However, when no analogies are found, new analogies may be constructed[1] or looked for. These new analogies should also be evaluated (see next stage). Note: Teachers or researchers who use the student self-developed analogy strategy do not need to construct new analogies.

Stage 4: Judge the appropriateness of the analogy to be used.

Initially, analogies can be evaluated according to the following criteria: a) Analogies which include familiar or easy to teach analogies (e.g., camera) should be given high priority to be used[2] (see the framework). Teachers who are not aware of the students' familiarity with the analog may use classroom oral questions for this purpose. Researchers as well as teachers may need to use questionares, clinical interviews for the same purpose. b) Analogies showing high complexity, i.e., many analogous attributes, should be given a considerable priority (see the framework). Teachers and researchers can use a checklist similar to that shown in figure 2 to assess this complexity. Their colleagues or others may work as raters of this checklist. Note: The analogy that meets these two criteria may be subjected to "pilot testing" on a small number of students. Preferably, this testing should include different characteristics of the analogy (see next step), different strategies of teaching and different mediums of presentation (see Stage 6). The feedback obtained from this testing may help the teachers and the researchers to make the right decisions regarding these characteristics, strategies and mediums.

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[1]There is no fool-proof system of constructing a new analogy (Mayer, 1983). Constructing analogies is mostly a creative type of thinking (Dreistadt, 1968)

[2]Sometimes the teachers or the researchers have to use an unfamiliar "analog". These "analogs" should be taught first until they become familiar to the learners.

Stage 5: Determine the characteristics of the analogy to be used.

Teachers and researchers need to determine the following characteristics of the analogy to be used (see the framework):

1. Degree of concreteness (physical, pictorial or verbal)
2. Number of the analogs included in the analogy ( single analogy or multiple analogy)
3. Format of the presentation (mixed format or separate format)

Note: Teachers may determine the above three characteristics in the light of many considerations, one is the feedback obtained form the above pilot testing or from their previous experience with the analogy to be used. For example, if a multiple analogy was previously shown to increase students' knowledge of the attributes of the "topic" compared with a single analogy, the teacher might choose to use this multiple analogy a second time. A further consideration is the teacher's knowledge of students' characteristics. For example, students who are concrete thinkers may need analogies in which both the "topic" and the "analog" are physical. Furthermore, the facilities available for teaching play a role in determining the characteristics of the analogy, for example, if there is no concrete model available for the "analog," the teacher may use a picture of the "analog" instead. Researchers may also determine the characteristics of the analogy according to the objective of the study. For example, if the objective of one study is to compare the effect of mixed format with the separate format, then both formats will be selected.

Stage 6: Select the strategy of teaching and the medium of presenting the analogy.

As indicated in the framework, there are 3 major strategies to teach the analogy: 1) student self-developed analogy; 2) guided-teaching strategy; and 3) expository-teaching strategy. In addition, there are many mediums of presenting the analog: 1) written medium, 2) oral presentation by the teacher, 3) audio cassette, television and slide presentations, 4) demonstrations, 5) role playing, 6) games, 7) manipulative models, 8) pictures, and 9) graphs.

Note: Teacher's slecetion of the strategy used and of the medium of presenting the analogy may depend on the same considerations that determine the characteristics of the analogy (see Stage 5). In addition the researchers' selection of the strategy and the medium is also determined according to the objective of his study.

Stage 7: Present the analogy to the learners.

The following recommendations are suggested for presenting the analogy to the learners:

1) Students who are not familiar with using analogies in their learning should be given a simple introduction to analogies. This introduction may include a definition of the "analogy" and how to learn by analogy proceeds (see the framework). The rationale for this introduction is that learners who are not familiar with "analogies" may not use them in their learning (Noel, Bonjog, and Young, 1980). Or, they may not use them correctly such as taking the relationship literally between the "analog" and the "topic."

2) The following sequence may be used to present the analogy to students (see Figure 4).

   a) The objective of the presentation is stated first. That is done to direct students' attention to the target learning task; the topic.

   b) The "analog" is introduced quickly if it is familiar to the students. The unfamiliar analogy might be taught with some depth or details until it becomes familiar to the learners.

   c) A statement that initially connects the "analog" to the "topic" is presented. This statement may raise the expectancy of the students of what is coming next.

   d) The analogous attributes are presented one at a time. Human beings do not attempt to handle all possible matches at once. Indeed,

OBJECTIVE STATEMENT

*"Class, today we are going to talk about why metals are good conductors of electricity.*

INTRODUCTION OF THE ANALOG

But, first, I want you to imagine that you are at the town fair. At the fair are two booths with a game which involves throwing a football through a series of five tires. If you throw three footballs through all five tires within a minute, you win a prize. In one of the two booths, the man operating the game has only two footballs; after you throw the two footballs, he must run to the end of the game booth, pick up the balls, and bring them back to you before you can throw again. In the other booth, the game operator has many footballs, and you can throw one right after another until your minute is up. If you could win a prize only after you threw three footballs through the tires within a minute, I'm sure you would rather play the game at the booth with many footballs; correct?

"Now let's imagine that in the booth with only two footballs, the five tires are lined up a bit irregularly. One tire juts out a little to one side, the next one a little to the other side, and so on. As a result, if we look down the center of the tires, we can see that the opening through the series of tires is only slightly larger than a football. In contrast, in the booth with many footballs, the five tires are perfectly aligned. The passage through the series of five tires is as large as the hole in the center of each tire.

"Now all of you, I'm sure, would prefer to play the game in the booth with many footballs where the tires are perfectly line up. The chances that you could throw three footballs through the tires in a minute are much greater at this booth.

CONNECTION STATEMENT

*"What does this example have to do with metals and current flow? Let's see. Metals are good conductors of electricity for many of the same reasons the booth with more footballs and perfectly aligned tires is preferable to you.*

Figure 4: Sequence of presenting the analogy to students.
(Continued on the following page)

| | |
|---|---|
| PRESENTATION OF ANALOGOUS ATTRIBUTES | First, metals have many free-floating electrons, while other materials have few free electrons. The chances that the electrons will move from one end of the material to the other are much greater when many electrons are present rather than just a few. This situation is similar to the booth where you were likely to throw several balls through the tires in a given time because more balls were available to be thrown. Metals also have a property relatable to the alignment of the tires. Second, metals have a highly regular internal structure; that is, all of the molecules in a metal are lined up in rows, and openings between the molecules run the length of the material. In contrast, nonmetals have a very irregular internal structure. Like the irregularly lined-up tires, on molecule juts out here, another there, so that very few open passages run the length of the material. Thus when electrons come shooting down the material, many of them collide with the molecules which block their flow. As a result, few electrons pass the length of the material. |
| TRANSFER STATEMENT | *"But is the movement of the electrons inside the metal exactly identical to the movement of the balls through the tires? Of course it is not.* |
| PRESENTATION OF IRRELEVANT ATTRIBUTES | "The electrons are different from the balls in many aspects: 1) electrons are very tiny, invisible particles while the balls are relatively large, observable bodies; 2) electrons move in random directions while the balls do not in this case, etc." (The teacher goes on and mentions other differences between the electrons and the balls and between the molecules and the tires.) |

Figure 4: Sequence of presenting the analogy to students. (The content of this analogy is modified from Royer and Allan, 1978, pp. 130-131.)

they can keep in mind only a few attributes at a time (Bruner, Goodnow, and Austin 1956). Preferably, the salient, observable, macroscopic and important analogous attributes need to be presented first.

e) A Transfer Statement is presented. This statement will move the students' attention from the previous context to the next context of learning. It will prepare the learner to expect that the irrelevant attributes will be discussed next.

d) Lastly, the irrelevant attributes are presented one at a time. Presenting these attributes could correct any misconceptions that could have resulted during the analogical learning (see the framework).

Stage 8: Evalute the outcomes of using the analogy in teaching

As indicated in the framework, this evaluation should proceed in the following steps:

1) determine whether or not students have used the "analog" to study the "topic".
2) assess the student's knowledge of the attributes of the topic.
3) Identify the misconceptions resulting from using the analogy

Stage 9: Revise the stages of the model

According to the feedback provided from all the above stages and especially the evaluation stage (#7), a continuous revision of all stages is recommended to improve the outcomes of using analogies in teaching. For example, if the evaluation stage shows that the learners' knowledge of the attributes of the "topic" is low, then some revision could be made such as the selecting of another "analog" that has more analogous attributes with the "topic," using other characteristics of the analogy, or other strategies of teaching, etc.

## SUMMARY

Cognitive psychologists have recently alluded the role the analogies might play in learning the unfamiliar topics. Analogies provide comparison which can expalin something difficult to understand by pointing out its similarities to something easy to understand or is already understood. Unfortunately, the use of analogy in science teaching has not been well covered; consequently, the use of analogies means different things to different people.

A model is proposed in this paper to guide teacning of analogies. This model is called: The General Model of Analogy Teaching (GMAT). A theoretical framework is developed from GMAT. The framework includes the following points: 1) definition of the analogy, 2) analogical learning, 3) variables related to analogical learning, 4) evaluating the outcomes of analogical learning, and 5) limitations of using analogies in teaching. The GMAT proceeds in the following nine stages: 1) Measure some ot the students' characteristics related to analogical learning in general, 2) Assess the prior knowledge of the students about the "topic" to be taught, 3) Analyze the learning material of the "topic" to be taught, 4) Judge the appropriateness of the analogy to be use, 5) Determine the characteristics of the analogy to be used, 6) Select the strategy of teaching and the medium of presenting the analogy, 7) Present the analogy to the students, 8) Evaluate the outcomes of using the analogy in teaching, and 9) Revise the stages of the model.

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